Renewable and Sustainable Energy Reviews 15 (2011) 1575–1592

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Fuel consumption and emission prediction by Iranian power plants until 2025

A. Mazandarani[a,*], T.M.I. Mahlia[a], W.T. Chong[a], M. Moghavvemi[b]

[a] Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b] Department of Electrical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 16 September 2010
Accepted 16 November 2010
Available online 12 January 2011

Keywords:
Alternative energy
Future energy trend
Iran national energy plan
Emission reduction
Electricity consumption and emissions

ABSTRACT

Electricity consumption has grown eleven-times within the last 30 years in Iran, which has resulted in about 118 Mtons in CO_2 emission in 2009. Economic growth in Iran depends on electricity; therefore, the trend of electricity generation should keep going in the future to guarantee this growth. In view of this need, the country has to build many new power plants. If most of them are thermal types, the CO_2 and other air pollutant emissions will increase and cause harmful environmental effects. In this paper, Iranian future power plant composition is investigated to predict the fuel consumption and emissions until 2025, which is the end of the country's 20-year vision plan (2006–2025). Government is planning to change the structure of power industries to a more variety and fewer shares of fossil fuel bases. The results showed that in this new composition, consumption of natural gas will increase by 47% and diesel by 50% by 2025. Coal consumption in power plants will reach to 10,826 ktons in the same time span. Whereas if the old composition continues in the future, fuel consumption will increase by 130%, 106% and 69% for natural gas, diesel and fuel oil respectively. It is also found that by 2025, CO_2 emission will increase another 2.1 times for the old and 1.6 times for the new power plant composition which government is planning to do.

Contents

* Corresponding author. Tel.: +98 917 714 4947.
E-mail address: afshin@mazandarani.ir (A. Mazandarani).

1364-0321/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.rser.2010.11.043

1. Introduction

Like any other energy sectors, electricity demand has greatly increased in Iran over the past years. Electricity usage has increased eleven-times over the past 30 years and nominal capacity has increased by equivalent to 1552 MW annually, and reached to 56,181 MW in 2009. It has been ranked 17 in nominal capacity and 19 in electricity generation in the world in 2005 [1,2]. Currently, there are six types of power plants in the country which generate most electricity using the gas turbines, steam turbines, combined cycles and hydro-powers and less than 1% is by diesel engines and only 0.1% is using the renewable wind energy. The share of each type of power plants in nominal capacity and electricity generation in 2009 is tabulated in Table 1 and is shown in Fig. 1. It has shown that in 2009, more than 96% of electricity produced is by fossil fuel based power generators. Although hydro-power plants have 13.7% of nominal capacity but because of the water shortage in the country, only about 3.3% of the electricity is generated by this type.

As power plants have been developed since long time ago, its structure has also been changed from time to time to meet the current electricity demands for the country. Fig. 2 shows the change in the pattern of nominal capacity composition from 1967 to 2009. This figure shows that in the last two decades (1989–2009) the share of the steam power plants decreased from 56% to 28%. While the share of both gas turbine and combined cycle together has been increased from 25% to 57%. The reasons for these changes are enormous gas resources in the country, high efficiency, and less emissions when natural gas use in combined cycle power plants compare to other thermal types.

The fuel types use in thermal power generators in Iran are fuel oil (heavy oil), diesel and natural gas. The power plants in the country is often use more than one fuel type depending on fuel availability over the year. Table 2 shows the types of fuel used by power plants. Concurrent with the development and change in the composition of power industries, the amount of fuel used has also changed. During 1979–2008, the consumption of natural gas in power plants has increased by 18.6 times and reached 43,411 Mm^3, while diesel and fuel oil has risen 3.1 and 8.4 times and reached 4398 and 8911 Ml respectively [2].

Power plant modernization and performance improvement also raise the share of combined cycle type causing an increase in the total thermal efficiency. The average efficiency of Iranian power plants in the past 30 years increased from 26% to 37% [3]. Therefore, there will be less fuel consumption to generate a unit of electricity compared with the old power plants.

It is well known that there is a direct relation between electricity consumption and economic growth. Therefore, electricity sector has to be developed to sustain this growth [4]. Iran has huge oil and gas resources accounting for 11% crude oil and 15.9% of natural gas of the world reserves. Moreover, there are considerable undeveloped gas resources in the country such as South Pars gas reservoir in the Persian Gulf that is equivalent to 6.7% of the total world resources or around 62% of Iranian natural gas reserves. According to these reservoirs, the dominance of fossil fuel based power plants in the future is predictable, and it is unlikely that the share of the other types becomes significant in the near future [5–7].

More electricity generation in thermal power plants will increase fossil fuel consumption, which subsequently results in an increase in emissions. Increasing fuel consumption in power plants or other energy sectors such as domestic, industry, and transport will also cause rapid resource depletion and reduce energy exports as the major sources of government income. Some studies suggest that energy sector in Iran is unsustainable and the country faces many problems. For example, the high growth rate of energy consumption due to over US$ 50 billion subsidies in all energy sectors including electricity sector, and about 22% electricity loss in transmission and distribution [1,6,8].

Comprehensive and optimized structure for the electricity generation of the country required both economic and environmental considerations. Because there are many alternative technologies and fuels available for this sector, it is important for policy makers to understand the implications of the different policies intended to meet the targets [9].

Many studies have been conducted to find methods for emissions abatement by improving technology. For instance, Holttinen studied the effect of wind energy on CO_2 abatement in the Nordic countries. They showed that if coal-fired power plants were replaced by wind turbines, it could reduce CO_2 emission by more than 0.6 kg/kWh [10]. Romeo, show that Spain can reduce CO_2 emission up to 90% by 2050 in an efficiency scenario with carbon capture and storage (CCS) and renewable energies. Therefore, the development of CCS projects in Spain is essential in order to maintain economic development without increasing CO_2 emissions and as an action response to Kyoto protocol targets [11]. The use of renewable energy could reduce the share of coal power plants from 44% to 39%, as well as decrease the cumulative emission of CO_2 by 8%, SO_2 by 3%, and NO_x by 4% in Vietnam [12]. In addition, renewable energy could help avoid installing 4400 MW of fossil fuel generating capacity, conserve domestic coal, and decrease coal and gases imports and improve energy security. The influence of different type of power generation technologies, espe-

Nomenclature

CF	power plant capacity factor (%)
CV	calorific value (kcal/l)
EF	emission factor in power plant (kg/m^3, kg/l)
EG	electricity generation (GWh)
EM	power plant emission (tons)
EP	emission per unit electricity generation (kg/kWh)
FC	fossil fuel consumption (Mm^3, ktons, Ml)
FE	fuel consumption per unit electricity generation (m^3/kWh, kg/kWh, l/kWh)
k, *C*	constant values
NC	power plant nominal capacity (MW)
NP	share of nominal capacity (%)
x	year predicted – year start
y	predicted value

Subscripts

f	fuel type consumed in power plant
i	in the year *i*
ng	natural gas
sf	substituted fuel

Superscripts

n	power plant type (coal-fired, combined cycle, diesel engine, gas turbine, hydro-power, non-hydro renewable and steam turbine)
p	emission type (CO_2, SO_2, NO_x and CO)

cially the potential role of natural gas combined cycle and nuclear power plants on CO_2 emission in Shanghai, China were discussed by Ref. [13].

Iran can improve electricity sector and increase sustainability by power plant improvements and technological advances in the transmission and distribution in order to reduce its losses. This will improve energy efficiency and help to postpone investment of the new power plants that are in most cases fossil fuel based. Clearly, this action is more cost-effective than developing new power plants. For example, the reduction of 3% of the 22% total losses is almost equivalent to the electricity generation in 1000 MW steam turbine or coal-fired power plants.

Fuel price and the cost of the power plant, the social, health and environmental costs are important factors to take into account in the electricity sector economical analyzes and in making decision for its structure. In addition, there may be also some global factors such as carbon trading at the national and international level [14]. Each country according to its energy resources, technical and economical abilities have many options for its power plant composition.

The purpose of this study is to estimate the future fossil fuel consumption and emissions in Iranian power plants. The effect of keeping the current composition and the new one which government plans to introduce and the effect of fuel switching to low carbon fossil fuels will be discussed. The results will show how each strategy influence the emissions and fuel consumption in the future electricity sector of the country.

2. Power plant composition in the future

For sustainable development and to increase energy security, the Iranian government plans to increase power plant diversity by using new types such as nuclear, coal and more renewable energies. Details of the potential government goals for changes in fuel sources composition and develop electricity sectors are collected from various sources and described in this paper. Despite all technical, economical, and political limitations that Iran may face in achieving the goal, these are considered as Iranian future power plant composition.

2.1. Nuclear power plants

Nuclear energy has been used to produce electricity for more than 50 years. In 2007, it provides about 17% of the world's electricity supply, 23% in Organization for Economic Co-operation and Development countries (OECD) and about 30% in Europe. Currently, around 438 reactors, representing a total capacity of 372 GW (2719 TWh) are in operation in the world and 54 reactors are still under construction [15–17]. According to the IAEA's 2006 projections, world nuclear power capacity is expected to expand to 414 GW in 2030 in the low estimates and to 679 GW in the high estimates [18]. According to Gorashi, Iran needs 15 GW nuclear power plants to be constructed within 30 years to secure a sustainable energy development [19]. Other reasons including the need for energy, superior technology achievement, creating diversity, energy security, and environmental advantages consider nuclear power plant development as a necessity for long-term plan energy supply [20]. In line with construction of 1000 MW pressurized water reactor type at Bushehr with Russia assistance, Iran is planning to operate a nuclear power plant of 360 MW using local technology [21]. In addition, construction of 5000 MW of nuclear power plants considered as a goal in the fifth 5-year national development plan (started 21 March 2010). Following the trend in the sixth and seventh country's 5-year plans by 2025, nuclear power plant will supply 10% of the electrical energy needs of the country equivalent to 20,000 MW [22].

However, as time commissioning of the Bushehr nuclear power plant has prolonged, it is not clear whether 10% supply of electricity needs from nuclear in 2025 is realistic or not. In addition, further concerns of the international community on the Iranian nuclear activities and due to some sanctions, it has increased the economic, political and social cost to execute the plan [23]. Nevertheless, in this study, the government target on constructing 20,000 MW nuclear power plants in 2025 is considered as the capacity for this type of power plants.

2.2. Fossil fuel based power plants

2.2.1. Steam turbines

Due to the high investment required for the construction of steam turbines, there is not much new development of this type of power plant in recent years. The capacity of steam power plants in 2004 was 15,229 MW with less than 1% growth per year reached 15,704 MW in 2009. It is expected that this trend will continue in the coming years and its share on capacity and electricity generation will be less than before. Other reasons for

Table 1
Electricity generation and nominal capacity share by power plant in Iran in 2009.

	Steam turbine (%)	Gas turbine (%)	Combined cycle (%)	Diesel engine (%)	Hydro power (%)	Wind energy (%)
Nominal capacity	28.0	33.1	24.3	0.8	13.7	0.2
Electricity generation	43.3	24.3	29.0	0.1	3.3	0.1

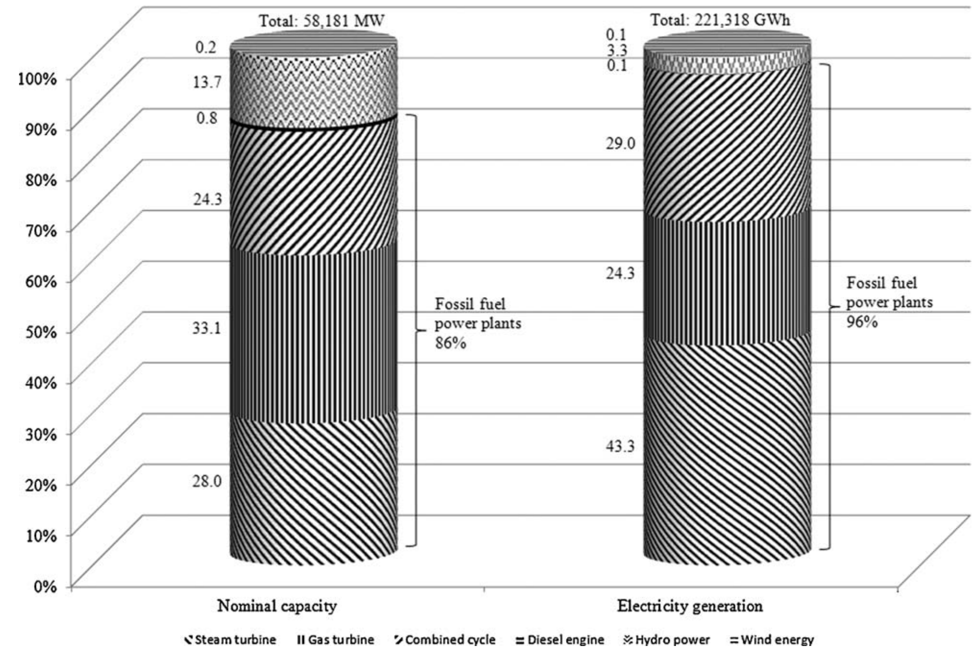

Fig. 1. Share of nominal capacity and electricity generation in Iranian power plants in 2009.

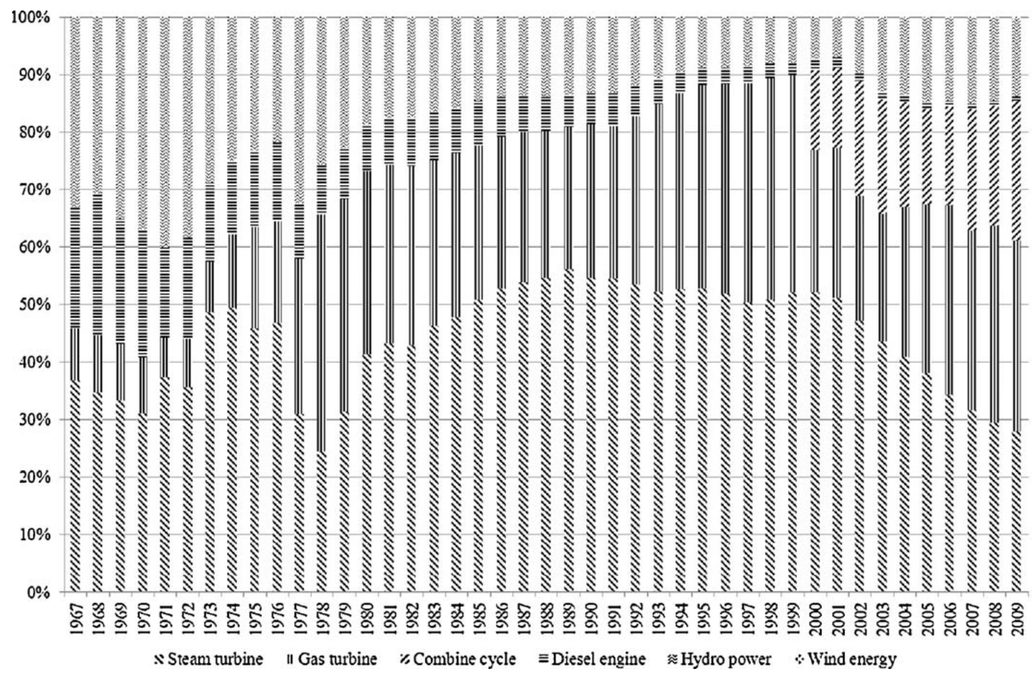

Fig. 2. Pattern of nominal capacity for each type of power plants in Iran from 1967 to 2009.

lack of development to the steam power plant are that they are base-loaded plants, and it is expected that in the coming years more concentration will be focused on peak load power plants. In addition, construction of nuclear power plants which is a kind of base-loaded plant, contributed to decreasing the share of steam power plants [21]. In this study, steam power plant capacity in the future is considered the same as the capacity in year 2009.

Table 2
Fuel types consumption in all types of Iranian thermal power plants.

Fuel type	Steam turbine	Gas turbine	Combined cycle	Diesel engine
Natural gas	x	x	x	–
Diesel	x	x	x	x
Fuel oil	x	–	–	–

x = fuel is consume in power plant, and (–) = fuel is not consume in power plant.

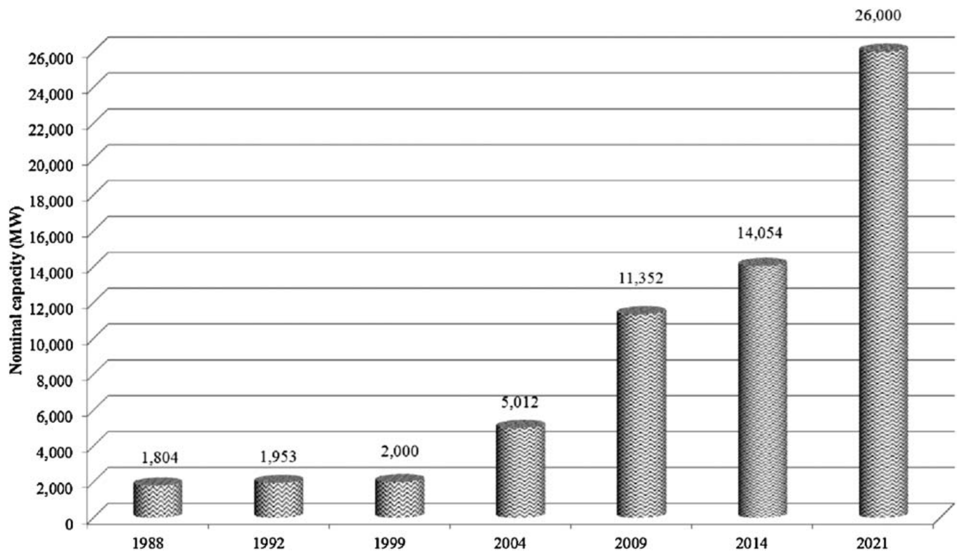

Fig. 3. Iranian hydro-power plants nominal capacity.

2.2.2. Diesel engines

The share of diesel engine power plants in Iran power capacity and also in electricity generation, decreased from 21% to less than 1% since 1967 [2]. The policy not to construct a new capacity for diesel engines is due to fuel prices and pollution problems. In this study no more investments are envisaged for this type of power plant and its total capacity considered to remain as 425 MW as in 2009.

2.2.3. Coal-fired

Iran has no coal-fired power plants at the moment, but having the resources of coal, has made them to start a coal-fired power plant in Zarand region and plans to increase its capacity after commissioning to 5000 MW in the long term [24]. In this study, the capacity of 5000 MW is considered for this type of power plant in 2025.

2.2.4. Gas turbines and combined cycles

The gas turbine power plants can be used in the rapid operation when the electricity demand is at its peak. Considering its fuel prices, gas turbine power plants have an economical justification, but from the viewpoints of national interests, it is one of the major energy policies in the country to make use of this fuel type at higher efficiency as combined cycle power plants [21]. Accordingly, the government plans to launch 27 steam units for the existing gas turbine power plants and many of them will become the combined cycle type [3]. Since 2000, the share of combined cycles and gas turbines type has grown rapidly and probably these types will have the largest share in electricity production in the country in the future. In this study, the capacity of gas turbines and the combined cycles in the future considered equivalent to the remaining capacity needed after the consideration of all other types.

2.3. Hydro-power plants

Hydro-power plants do not discharge air pollutant emissions and provide cheap electricity production and other benefits. In addition, due to maneuverable operation, they are important for the network stability. In recent years, despite drought which has reduced their share of electricity generation, the construction process of hydro-power plants has increased and several huge projects are under feasibility, study and construction. Based on the country's 20-year vision plan (2006–2025), the entire hydro-power capacity should be extracted and exploited [25]. Fig. 3 shows the capacity growth of hydro-power plants in the country [26].

2.4. Non-hydro renewable energies

Although most of the Middle East countries are rich in fossil energy resources, the use of Renewable Energy Sources (RES) has started to be an interesting issue for scientific communities and governments [27]. Energy Information Administration (EIA) predicted that renewable energies are projected to account for a modest 3% of the Middle East total electricity generation by 2030 [28].

Iran is a developing country with high rate of electricity consumption. In order to secure the supply of electrical energy, renewable energy should play an important role to help the sustainable development. Especially in Iran where most different types of RES are available and are also possible to be implemented for gaining required energy supply [29]. According to the objectives of the fourth 5-year plan, the government will increase the share of electricity production from these sources to 1% [30]. The government policy to purchase electricity produced from renewable resources from private sector will encourage investment in this sector. Furthermore, because of reduction in costs due to technological development, it is expected to speed up the growth to achieve the goal as soon as possible [6]. In Iran, the renewable sources of energy including wind, solar and geothermal will account for 3% of the country's nominal electricity generation capacity [31].

2.4.1. Wind energy

Due to Iran's geographical location, it has a good potential for the production of electricity using wind energy. Renewable energy organization of Iran (SUNA) has provided the national wind map (wind atlas) shown in Fig. 4 [32]. Total potential for wind power was initially estimated as 30,000 MW [33]. In recent years, various activities have been done to implement wind energy for the electricity generation and the application of wind energy has been developed very fast [34]. Since 2001, the use of wind energy has been growing rapidly and its capacity increased 30% annually and reached 92 MW in 2009. Finally, based on the next country's development plans, 2500 MW of wind turbines will be developed [3].

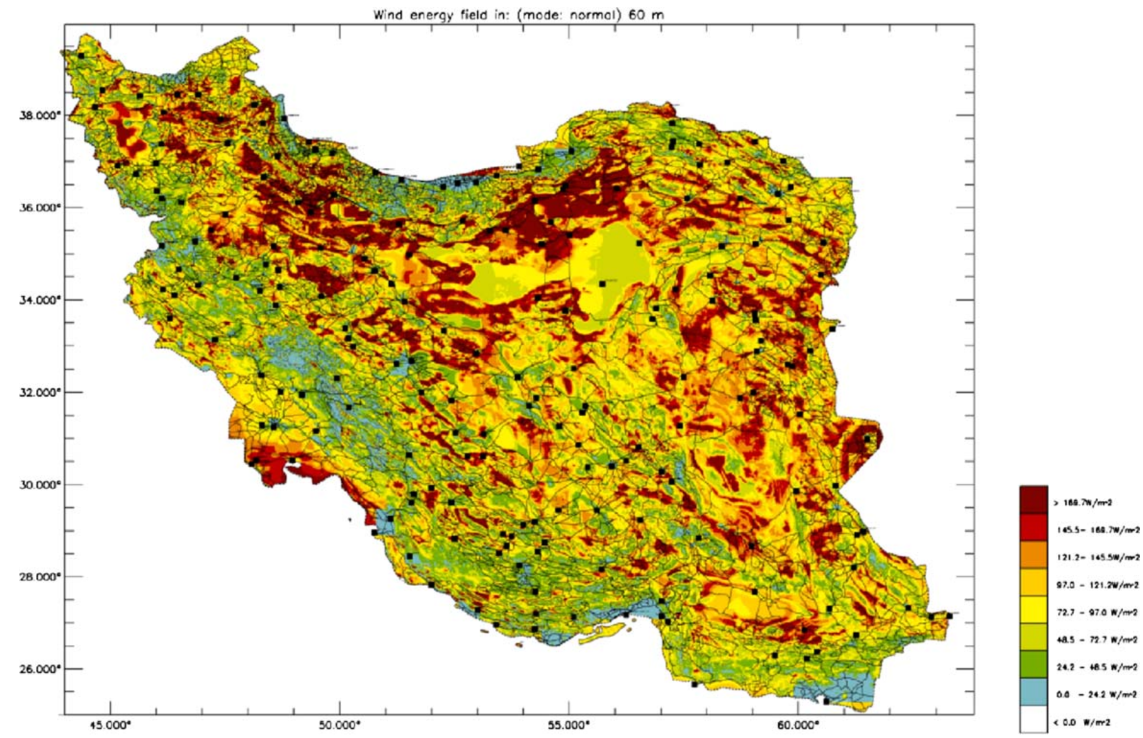

Fig. 4. Wind atlas map of Iran.

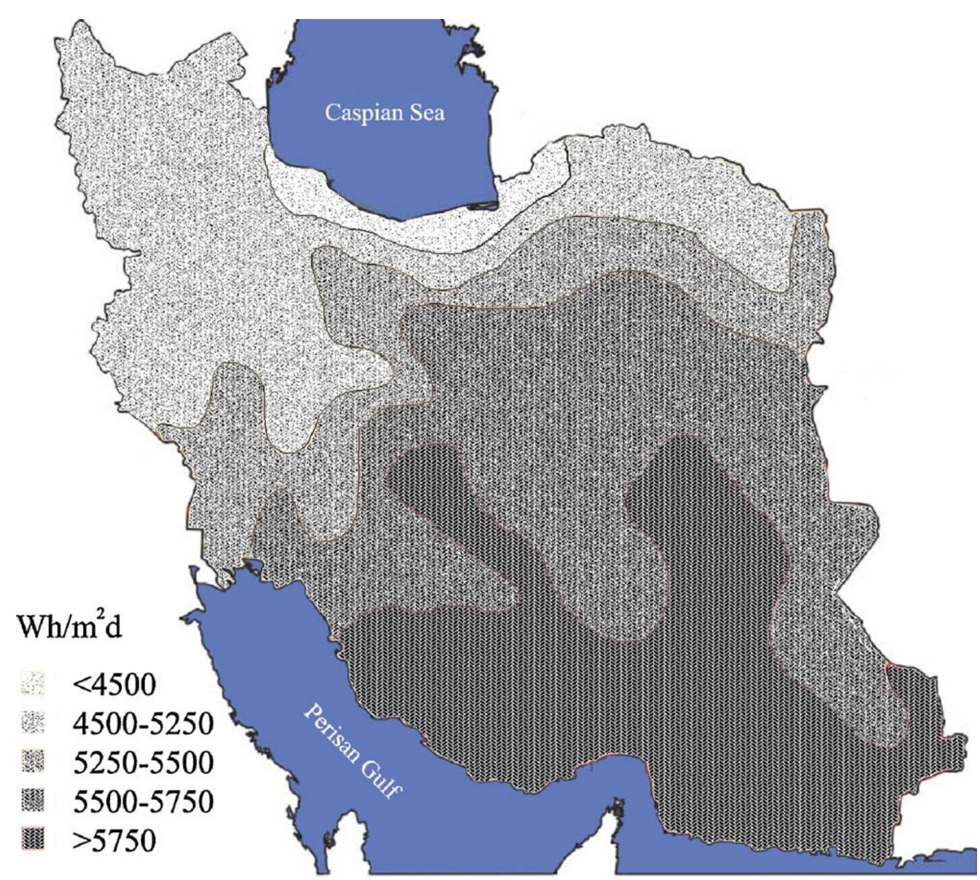

Fig. 5. Solar radiation in Iran.

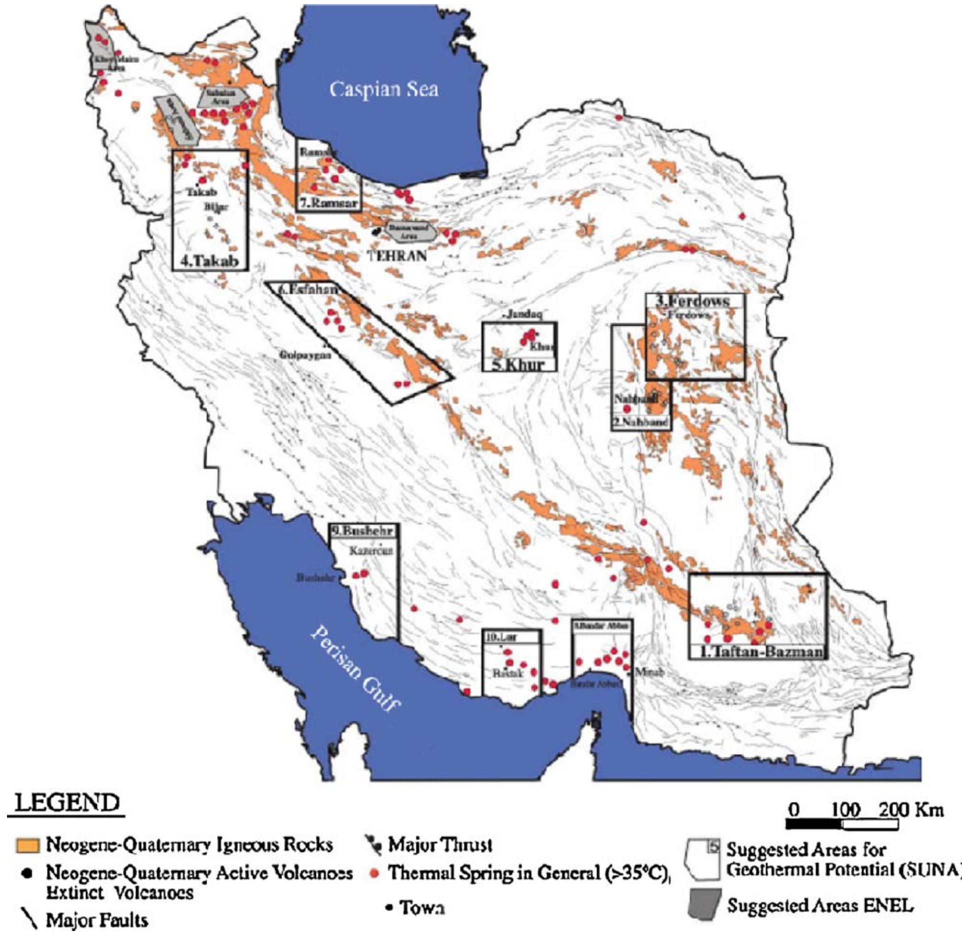

Fig. 6. Geothermal potential of Iran.

2.4.2. Solar energy

The average solar radiation for Iran is about 5.3 kWh/m^2/day and it is even higher in the central region of Iran, with more than 7.7 h/day (more than 2800 h/year) as depicted in Fig. 5 [35,36]. The first integrated solar combined cycle system (ISCC) that is the biggest of its type of power plants in the Middle East is under construction in Yazd. Technical and economic assessment showed that this is the most suitable project for renewable energy sources in Iran [37]. A great amount of solar energy potential and environmental interest are among the main considerations that led the Ministry of Energy to define, support and install the first 250 kW pilot solar thermal power plant in Shiraz [6,38]. The Center of Renewable Energy Research and Application (CRERA) and Atomic Energy Organization of Iran (AEOI) has conducted and completed many research projects in the area of solar energy. For example, the design and simulation of solar water pumps, solar water distillation of various types, design, manufacture, and simulation of solar collectors of different types, solar refrigerator and design and manufacture of solar air heaters [29].

2.4.3. Geothermal energy

It is indicated that 8.8% of Iran as prospected for geothermal power plant potential areas for about 18 fields [39]. The internal geothermal energy has been estimated to provide about 1400 MW of power for the consumers in Iran [40]. Studies by CRERA showed that 10 promising areas are identified all around Iran since 1995 (see Fig. 6) [41]. Ministry of Energy has started building the first geothermal power generation in one of these areas in Meshkinshahr at the North West of Iran. It is predicted that in the phase I, about 5 MW and in the phase II, about 55 MW electricity will be produced from these projects [6].

3. Methodology

3.1. Future fuel consumption and emission

The power plant development in Iran, with thermal power plant dominance will certainly cause more emissions in the future. To estimate the future emissions, it is essential to know the power plant developmental pattern. This study mainly focuses on the new power plant composition which government is planning to do. Besides, to understand the condition of fuel consumption and emissions in the future, two other alternative scenarios will be discussed.

The scenarios are tools for ordering perceptions about alternative future environments and the result might not be an accurate picture of tomorrow, but may give a better decision about the future. Regardless of how things could actually be, both the analyst and the decision maker will have a scenario that resembles a given future and will help researchers consider both possibilities and consequences of the future [42]. In doing so, the future power plant composition presented in Section 2 considered as the first scenario. Two more scenarios are another power plant composition and fuel type switching that evaluated for timeframe 2025, which is the end of the Iran's 20-year vision plan.

3.1.1. Scenario 2 (old composition)

In this scenario, the fuel types and the composition of power plants in the future are assumed to be as the same as in year 2009. No improvement in technology, change in the power plant composition and fuel consumption or apply in long term policies has been considered. In other words, this is the simplest way to simulate the emissions and fuel consumption in future.

3.1.2. Scenario 3 (fuel switching)

The difference of the first two scenarios was the composition of power plants. While in this scenario, the main point is the fuel switching; power plant composition will remain the same as the first scenario.

Fuel type selection for power plants depends on many considerations such as fuel price, plant location, fuel availability, environmental concern and even short-term, medium-term, and long-term policies of the electricity generation in the country. The main fuel in most thermal power plants in Iran is natural gas but due to lack of access to natural gas or being away from the main national gas pipelines or also pressure drop in the pipelines (due to more use of domestic consumption in the winter) many of them use other alternative fuels to meet the power demand. As some countries are seeking to reduce their emissions by converting to low carbon content type of fuel, the effect of stable supply of natural gas and reduction in the use of liquid fuels in thermal power plants are being investigated in this scenario. Supplying 100% energy from natural gas and eliminating diesel are considered for gas turbines and combined cycle power plants. For steam turbine power plants, diesel is used at the starting stage. For this reason, using natural gas instead of only fuel oil has been evaluated.

3.2. Nominal capacity prediction

There are several methods for predicting electricity demands in the future, which are affected by various factors. These factors are the energy prices, per capita gross domestic product (GDP), population, weather, customer income, etc. [43]. However, these factors are not taken into account in this paper and the trend of power capacity is considered similar to previous years. The method used to estimate long-term time series forecasting is polynomial curve fitting. This method attempts to describe the relationship between a variable X as the function of available data and response Y that seeks to find the smooth curve which best fits the data, but does not necessarily overtake through any data points. Mathematically, a polynomial equation of order k in X is an expression of this form [44]:

$$Y = C_0 + C_1X + C_2X^2 + \cdots + C_kX^k \quad (1)$$

3.3. Power plants nominal capacities

The nominal capacity in power plant type n can be calculated by the following equation:

$$NC^n = \frac{NP^n \times NC}{100} \quad (2)$$

For the second scenario, the share of nominal capacities considered as the same as 2009. In this scenario, nominal capacity for each type of power plants can be calculated by multiplying its share with the total nominal capacity of the country in that particular year. For the first and third scenarios, nominal capacities or their shares in 2025 already presented and described in Section 2. For 2010–2024 since the date of launching new power plants is not specified, linear prediction will be applied for estimation.

3.4. Capacity factor

The power plant capacity factor is the ratio of the electricity generated by power plant over a period of time (e.g. 1 year equivalent to 8766 h) and its generation operated at full nominal capacity for the entire time. In this paper, it is necessary to calculate this value to estimate the future electricity generation by thermal power plants. The average value of capacity factors in the last years will be considered for its value in the future. The trend of change in capacity factors of each thermal plant type in the past years can be calculated by the following equation:

$$CF_i^n = \frac{EG_i^n}{NC_i^n \times 8.766} \times 100 \quad (3)$$

3.5. Future electricity generation

The future electricity generation by power plants can be calculated by the following equation:

$$EG_i^n = \frac{CF^n \times NC_i^n \times 8.766}{100} \quad (4)$$

3.6. Fuel consumption per unit electricity generation

The fuel f consumption per unit electricity generation in power plant type n in the year i can be calculated by the following equation:

$$FE_{if}^n = \frac{FC_{if}^n}{EG_i^n} \quad (5)$$

3.7. Fuel consumption in the future

Total fuel consumption in thermal power plants in the future estimated by multiplying the average fuel consumption per unit electricity generation by power plants in last years and electricity generation which predicted for the future. This can be calculated by the following equation:

$$FC_{if}^n = FE_f^n \times EG_i^n \quad (6)$$

3.8. Fuel consumption in fuel switching scenario

In the third scenario due to replacement of fuel oil with natural gas, the consumption of fuel oil in power plants is eliminated. Diesel consumption used in diesel engines or as the starter in steam turbines can still be calculated by Eq. (6). In fact, natural gas fuel (ng) should compensate for liquid fuels thermal energies, its excess volume use can be calculated by the following equation:

$$FC_{ng}^n = \frac{CV_{sf}}{CV_{ng}} \times FC_{sf}^n \quad (7)$$

The substituted fuel (sf) for gas turbine and combined cycle is diesel and for steam turbine is fuel oil. Natural gas caloric value depends on the source of fuel, however in this paper the average value has been considered in the calculation.

3.9. Emissions in the future

The methodology used to evaluate emissions in power plants is the one recommended by the Emissions Inventory Improvement Program of the US Environmental Protection Agency. An emission factor is a representative value that attempts to relate the quantity of a pollutant released into the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant

(e.g., kilograms of particulate emitted per litter of diesel burned). In most cases, these factors are simply the averages of all available data of acceptable quality, and are generally assumed to be representative of the long-term averages for all facilities in the source category (i.e., a population average) [45].

The emission factor of a fuel will be different based on the power plant type. As mentioned in Table 2, all thermal power plants (except diesel engines) use more than one type of fossil fuels. Therefore, emission factor for each fuel such as diesel will be different from steam turbine, gas turbine and diesel engine power plants.

The pollutant p emissions per unit electricity generation for power plant type n is calculated by multiplying the emission factor and average fuel consumption per unit of electricity generation in respective power plant in the last years, which can be calculated by the following equation:

$$EP^{np} = EF_f^{np} \times FE_f^n \tag{8}$$

Total annual emission is equal to summation of emission per unit of electricity generation multiply by the amount of electricity generated by the respective power plant in the year. This can be calculated by the following equation:

$$EM_i^p = \sum_n EP^{np} \times EG_i^n \tag{9}$$

For fuel-switching scenario, emissions can be calculated by multiplying the emission factor by the amount of fuel consumed. Therefore, the total emission p of fuel f in power plant type n, can be calculated by the following equation:

$$EM^p = \sum_n \sum_f EF_f^{pn} \times FC_f^n \tag{10}$$

4. Results and discussions

4.1. Collected data

The data used for this study are country's total nominal capacity and the electricity generation in the past 30 years (1980–2009) and fuel consumption of each type of power plants from 2001 to 2009. These data are collected from Ref. [46] and shown in Tables 3–5. Emission factors for each fuel type in all types of thermal power plants are presented in Table 6. SO_2 emission factor can be calculated by multiplying the weight percent sulfur in the fuel by the numerical value preceding sulfur (S). The fuel oil and diesel produced by the local refineries are high in sulfur content about 2.5–3.5 wt% [47] and 500–10,000 ppm [48]. Sulfur content in natural gas is assumed to be 2000 grains/10^6 scf and natural gas density 0.05 lb/ft^3. In the coal-fired power plant, the emission per unit of electricity generation is collected from Ref. [49] and shown in Table 7 where the coal consumption per unit electricity generation in coal-fired power plants is assumed to be 380 tons/GWh based on Ref. [50]. Calorific values are essential in calculating natural gas consumption in fuel switching scenario. These values are 9790 kcal/l for fuel oil, 9232 kcal/l for diesel and between 8.509 and 9.099 kcal/l for natural gas [46].

Table 3
Nominal capacity of Iranian power plants from 1980 to 2009.

Year	Total nominal capacity (MW)
1980	9628
1981	10,232
1982	10,308
1983	10,922
1984	11,419
1985	12,369
1986	13,011
1987	13,311
1988	13,681
1989	14,442
1990	14,803
1991	14,848
1992	16,313
1993	18,212
1994	20,413
1995	21,914
1996	22,420
1997	23,257
1998	24,437
1999	25,205
2000	27,188
2001	28,944
2002	31,518
2003	34,328
2004	37,301
2005	41,032
2006	45,288
2007	49,413
2008	52,945
2009	56,181

4.2. Power capacity in the future

Based on the polynomial curve fitting method described in Section 3, the total power plant capacity in coming years is estimated by the assessment of historical data from 1980 to 2009. Using Eq. (1) and the data in Table 3, the total nominal capacity equation is estimated by the following equation:

$$y = 64.715x^2 - 548.86x + 12287 \quad R^2 = 0.988$$

Iran's historical nominal capacity for the past thirty years and its forecasted value until 2025 is shown in Fig. 7. Accordingly, the total capacity of Iranian power plants in 2025 is estimated to be about 124,000 MW. This value shows that the expected demand for electricity during the coming 16 years would require the installation of as many power plant capacities as installed in the entire past years. It also shows that in order to maintain the trend of the country

Table 4
Nominal capacity and electricity generation in Iranian thermal power plants from 2001 to 2009.

Year	Steam turbine		Gas turbine		Combined cycle		Diesel engine	
	(MW)	(TWh)	(MW)	(TWh)	(MW)	(TWh)	(MW)	(TWh)
2001	14,776	83,510	7565	20,344	4060	17,899	533	328
2002	14,840	84,260	6857	17,531	6290	27,586	490	356
2003	14,904	87,670	7663	17,697	6832	32,895	493	290
2004	15,229	90,716	9710	24,979	6832	36,250	493	252
2005	15,577	93,383	12,050	32,129	6832	36,194	493	212
2006	15,553	92,481	14,862	41,235	7836	40,343	418	220
2007	15,598	94,228	15,433	37,604	10,479	53,796	418	225
2008	15,598	97,201	18,077	54,911	11,117	57,015	418	204
2009	15,704	95,771	18,593	53,846	13,664	64,142	425	124

Table 5
Composition of fuel consumption in Iranian power plants from 2001 to 2009.

Year	Fuel type	Steam turbine	Gas turbine	Combined cycle	Diesel engine
2001	Natural gas (Mm^3)	15,059	6342	3600	–
	Diesel (Ml)	79	1122	366	100
	Fuel oil (Ml)	6799	–	–	–
2002	Natural gas (Mm^3)	15,930	5410	6259	–
	Diesel (Ml)	74	1138	332	109
	Fuel oil (Ml)	6275	–	–	–
2003	Natural gas (Mm^3)	17,893	5532	6843	–
	Diesel (Ml)	44	948	361	86
	Fuel oil (Ml)	4938	–	–	–
2004	Natural gas (Mm^3)	18,127	7372	7183	–
	Diesel (Ml)	47	1456	608	78
	Fuel oil (Ml)	5736	–	–	–
2005	Natural gas (Mm^3)	18,343	9506	7204	–
	Diesel (Ml)	64	1862	660	62
	Fuel oil (Ml)	6329	–	–	–
2006	Natural gas (Mm^3)	16,539	10,968	7732	–
	Diesel (Ml)	90	3344	1203	65
	Fuel oil (Ml)	7587	–	–	–
2007	Natural gas (Mm^3)	16,164	10,435	10,377	–
	Diesel (Ml)	132	2271	2088	66
	Fuel oil (Ml)	8435	–	–	–
2008	Natural gas (Mm^3)	16,792	15,262	11,357	–
	Diesel (Ml)	70	2970	1299	59
	Fuel oil (Ml)	8911	–	–	–
2009	Natural gas (Mm^3)	15,726	14,737	12,841	–
	Diesel (Ml)	49	3037	1812	37
	Fuel oil (Ml)	9541	–	–	–

development, the annual growth of 5.1% of the nominal capacity in power plants is required until 2025.

4.3. Future capacity factors

The trends of capacity factors in the past years calculated using Eq. (3) and data in Table 4. The results are compiled in Table 8 and are shown in Fig. 8.

Several components influence the power plant capacity factors including life span, purpose, overhaul maintenance, fuel supply, and technology used in power plants. Fig. 8 shows that this factor for the base-loaded power plants (e.g. steam turbine) is always higher than peak-load power plants, which were usually added to the network at the peak electricity demand hours.

The average capacity factors for steam turbine, gas turbine, combined cycle and diesel engines has been evaluated 67.8%, 30.3%, 56.2% and 6.0% respectively. In this study, capacity factor of the coal-fired power plants is assumed 65.0% [51].

4.4. Power plant nominal capacities in the future

Based on the future power plant composition, described in Section 2, the amount of nominal capacities in each type of power plant is calculated and presented in Table 9. Fig. 9 shows the nominal capacities and their shares in new power plant composition in 2025. Fig. 10 shows the pattern of nominal capacity composition from 2009 to 2025. This figure shows that power plant diversity will increase to ten (five thermals, four renewables and a nuclear). It also shows that the share of thermal power plants will decrease

Table 6
Emission factors used for estimating emission in thermal power plants.

Fuel type	Power plant type	Emission				Unit
		CO_2	SO_2	NO_x	CO	
Natural gas	Steam turbine	1.86	9.32×10^{-6}	4.35×10^{-3}	1.31×10^{-3}	kg/m^2
	Gas turbine or combined cycle	1.74	0.0149S	5.07×10^{-3}	1.30×10^{-3}	kg/m^2
Fuel oil	Steam turbine	2.93	0.0188S	5.64×10^{-3}	6.00×10^{-4}	kg/l
Diesel	Steam turbine	2.68	0.0188S	3.84×10^{-3}	6.00×10^{-4}	kg/l
	Gas turbine or combined cycle	2.61	0.0168S	1.46×10^{-2}	5.48×10^{-5}	kg/l
	Diesel engine	2.73	4.82×10^{-3}	7.33×10^{-2}	1.58×10^{-2}	kg/l

S% indicates percentage of Sulfur in the respective fuel, by weight.

Table 7
Emissions per unit of electricity generation in coal-fired power plants.

SO_2 (kg/GWh)	CO_2 (kg/GWh)	NO_x (kg/GWh)	CO (kg/GWh)
13,900	1,180,000	5200	200

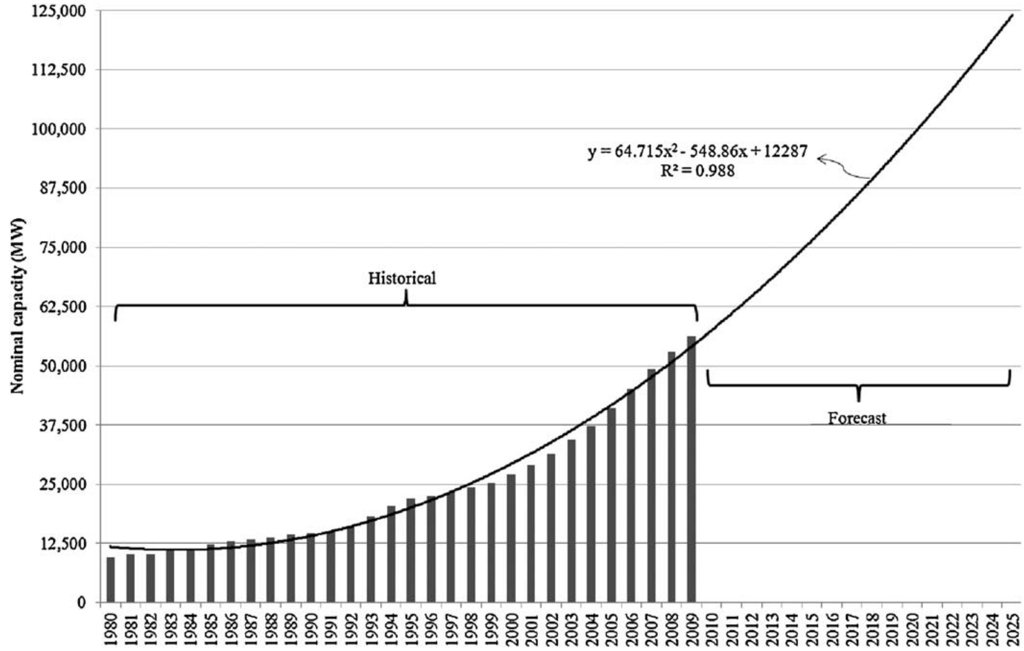

Fig. 7. Historical data and forecasted nominal capacity of Iranian power plants from 1980 to 2025.

Table 8
Capacity factor in Iranian thermal power plants from 2001 to 2009.

Year	Steam turbine (%)	Gas turbine (%)	Combined cycle (%)	Diesel engine (%)
2001	64.47	30.68	50.29	7.02
2002	64.77	29.17	50.03	8.28
2003	67.10	26.34	54.93	6.72
2004	67.95	29.35	60.53	5.83
2005	68.39	30.42	60.43	4.91
2006	67.83	31.65	58.73	6.00
2007	68.91	27.80	58.56	6.14
2008	71.09	34.65	58.51	5.57
2009	69.57	33.04	53.55	3.33

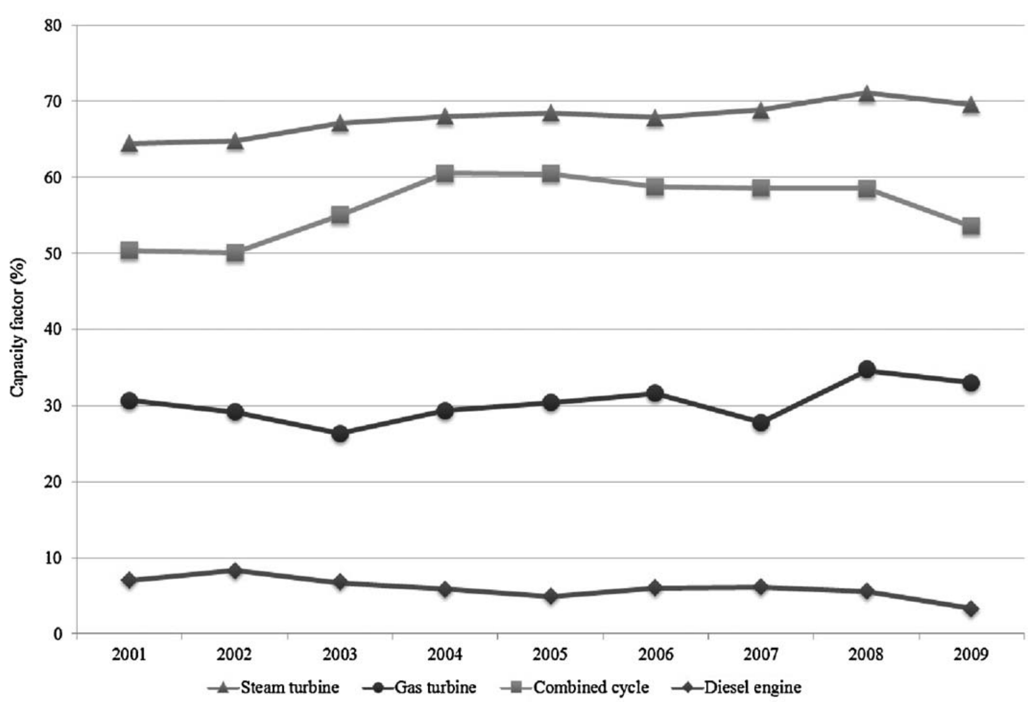

Fig. 8. Iranian thermal power plants capacity factor from 2001 to 2009.

Table 9
Nominal capacity prediction in Iranian power plants from 2010 to 2025.

Year	Steam turbine (MW)	Gas turbine (MW)	Combined cycle (MW)	Diesel engine (MW)	Coal-fired (MW)	Hydro-power (MW)	Non-hydro renewables (MW)	Nuclear (MW)	Total (MW)
2010	15,704	18,790	13,861	425	95	8049	161	378	57,463
2011	15,704	19,333	14,404	425	355	9001	349	1419	60,992
2012	15,704	19,896	14,967	425	625	9988	545	2498	64,649
2013	15,704	20,479	15,550	425	904	11,010	748	3615	68,436
2014	15,704	21,082	16,153	425	1193	12,067	957	4771	72,353
2015	15,704	21,705	16,776	425	1491	13,159	1174	5964	76,399
2016	15,704	22,348	17,419	425	1799	14,286	1397	7196	80,574
2017	15,704	23,010	18,081	425	2117	15,448	1627	8466	84,879
2018	15,704	23,693	18,764	425	2444	16,645	1865	9774	89,313
2019	15,704	24,395	19,466	425	2780	17,876	2109	11,120	93,877
2020	15,704	25,118	20,189	425	3126	19,143	2360	12,505	98,570
2021	15,704	25,860	20,931	425	3482	20,445	2618	13,927	103,392
2022	15,704	26,622	21,693	425	3847	21,781	2883	15,388	108,344
2023	15,704	27,404	22,475	425	4222	23,152	3155	16,887	113,425
2024	15,704	28,207	23,278	425	4606	24,559	3434	18,425	118,636
2025	15,704	29,029	24,100	425	5000	26,000	3719	20,000	123,976

from 85% to 60% in the new power plant composition in the future.

4.5. Fuel consumption per unit electricity generation

The average fuel consumption per unit electricity generation for each type of thermal power plants from 2001 to 2009 is calculated using Eq. (5) and data from Tables 4 and 5. The results are tabulated in Table 10.

4.6. Future fuel consumption

To calculate the future fuel consumption, it is necessary to estimate electricity generation in thermal power plants in the future. In the second scenario, electricity generation estimated using Eq. (2) and average capacity factor that was presented in Section 4.3, in Eq. (4). In the first and third scenarios, electricity generation was calculated using capacity factor and future nominal capacities presented in Table 9, in Eq. (4).

All types of fuel consumption (including coal) in each type of thermal power plants in the future are calculated using Eq. (6). To calculate additional natural gas utilization in the third scenario and to compare with the first scenario, fuel's calorific values are used in Eq. (7). Total fuel consumption in all power plants for each scenario are tabulated in Table 11 and shown in Fig. 11. It shows the amount of fossil fuels consumed in 2009 and amount of fuels required for selecting each scenario in 2025.

The results show that in the new power plant composition, the consumption of natural gas 47% and diesel 50% will increase. In addition, coal consumption in coal-fired power plants will reach 10,826 ktons. The total coal production in the country in 2007 was about 2500 ktons. Therefore, providing this size of coal to use in coal-fired power plants will require a huge amount of investment to increase productions or imports [6].

In the second scenario where the same composition of power plants as in 2009 is assumed, all types of fuel consumption will increase by 130%, 106% and 69% for natural gas, diesel and fuel oil respectively. Meanwhile, in the third scenario, with the replacement of liquid petroleum with natural gas, only in 2025 the consumption of 7321 Ml fuel oil is eliminated and diesel consumption is decreased 97 vol%, equivalent to 7261 Ml. On the other hand,

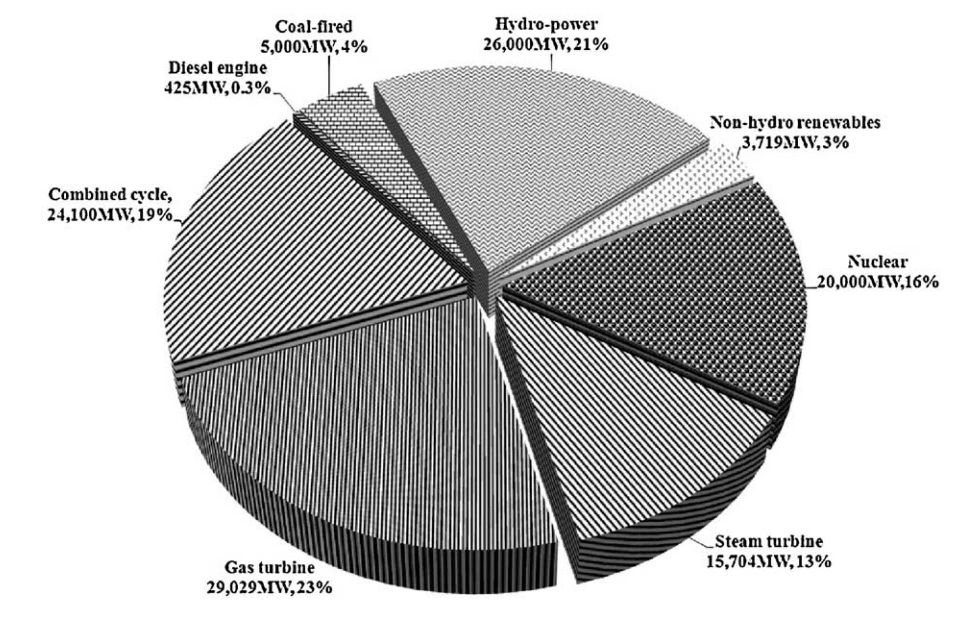

Fig. 9. Nominal capacity (MW and %) in Iranian new power plant composition in 2025.

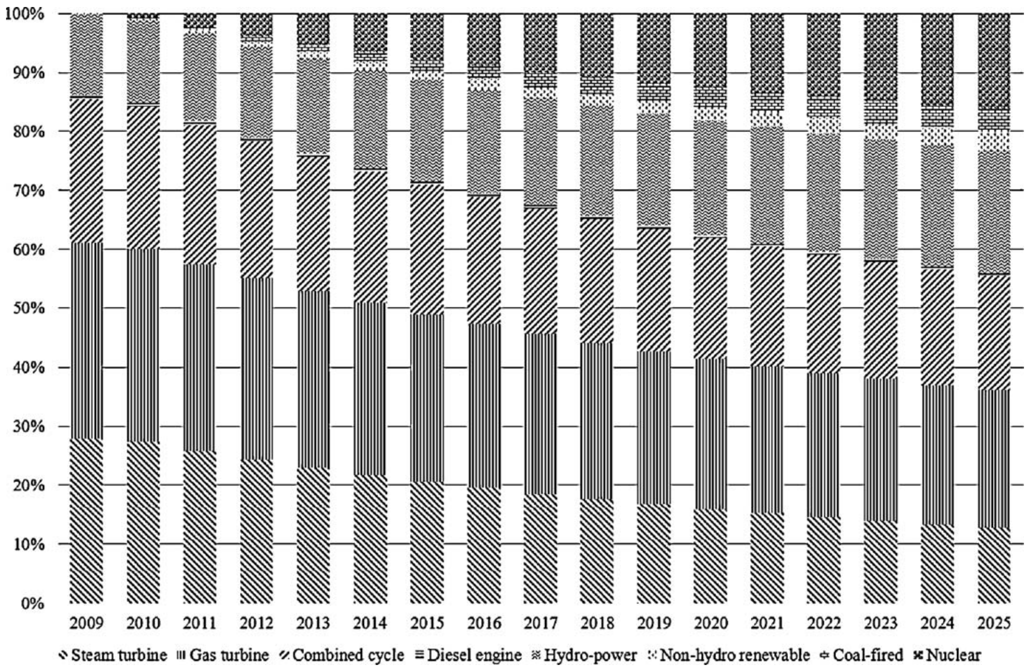

Fig. 10. Pattern of nominal capacity for each type of power plants in Iran from 2009 to 2025.

Table 10
Average fuel consumption per unit of electricity generation in Iranian thermal power plants.

Fuel type	Steam turbine	Gas turbine	Combined cycle	Diesel engine
Natural gas (m^3/kWh)	0.1841	0.2910	0.2019	–
Diesel (l/kWh)	0.0008	0.0602	0.0220	0.2981
Fuel oil (l/kWh)	0.0785	–	–	–

natural gas consumption will increase 15,755 Mm^3. In view of fuel supply in this scenario, theoretically it is possible for the country to switch the fuel to natural gas, because Iran is rich in natural gas resources, which is used by many power plants. Nevertheless, it should be made available over the year especially in the winter when domestic consumption is maximum. In addition, it is necessary for those that previously did not use natural gas to carry out pipeline and to prepare them technically to use this type of fuel.

4.7. Emission per unit electricity generation

Emission per unit of electricity generation in the power plants is calculated using data from Tables 6 and 10 in Eq. (8). The results are tabulated in Table 12.

The results found are similar to the data that experimentally was calculated using analysis and measurement of flue gases of Iran fossil-fuel power plants (steam turbine, gas turbine and combined-cycle types) [52].

4.8. Emissions in 2025

The amount of emissions calculated using electricity generation predicted in thermal power plants and emissions per unit electricity generation in Iranian thermal power plants. In the fuel-switching scenario, total emission is calculated using emission factors and fuel consumptions data in Eq. (10). The results are tabulated in Table 13 and presented in Figs. 12–15 for CO_2, SO_2, NO_x and CO respectively.

4.8.1. CO_2 emission

Fig. 12 presents CO_2 emission from electricity sector in Iran in different scenarios compared with emission in 2009. The results showed that in the new composition (first scenario) CO_2 emission was 1.6 times higher than those in 2009. If the old structure of electric power industries continues (second scenario), CO_2 emission will increase 2.1 times by 2025. This means that the new composition causes CO_2 abatement for about 65 Mtons in 2025. In addition, the results show that after natural gas substitutions, the total emission reduced by 6%

Table 11
Fuel consumption prediction in thermal power plants in each scenario in 2025.

	New composition (Scenario 1)	Old composition (Scenario 2)	Fuel switching (Scenario 3)
Natural gas (Mm^3)	63,611	99,652	79,366
Diesel (Ml)	7401	10,149	140
Fuel oil (Ml)	7321	16,156	–
Coal (ktons)	10,826	–	10,826

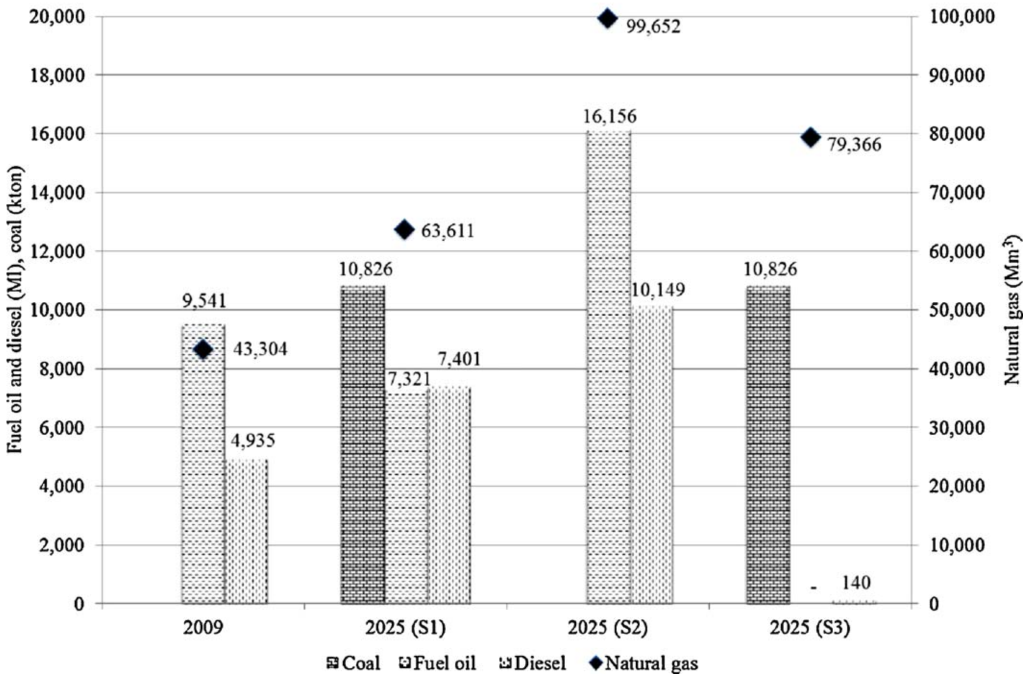

Fig. 11. Power plants fossil fuel consumption in 2009 and three scenarios in 2025.

Table 12
Emission per unit of electricity generation in Iranian thermal power plants.

	CO_2 (kg/kWh)	SO_2 (kg/kWh)	NO_x (kg/kWh)	CO (kg/kWh)
Steam turbine	5.75×10^{-1}	4.44×10^{-3}	1.30×10^{-3}	2.88×10^{-4}
Gas turbine	6.64×10^{-1}	5.33×10^{-4}	2.36×10^{-3}	3.81×10^{-4}
Combined cycle	4.09×10^{-1}	1.96×10^{-4}	1.35×10^{-3}	2.64×10^{-4}
Diesel engine	8.13×10^{-1}	1.44×10^{-3}	2.18×10^{-2}	4.71×10^{-3}

Table 13
Emissions in 2009 and emissions prediction in each power plant and each scenario in 2025.

Emission (tons)	Year (scenario)			
Power plant type	2009	2025 (S1)	2025 (S2)	2025 (S3)
CO_2				
Steam turbine	57,386,356	53,666,601	118,427,776	47,210,496
Gas turbine	33,612,842	51,296,603	72,504,056	47,665,692
Combined cycle	27,111,770	48,583,157	60,786,094	46,542,970
Diesel engine	100,836	180,932	399,267	180,932
Coal-fired	–	33,617,610	–	33,617,610
Total	118,211,804	187,344,902	252,117,194	175,217,699
SO_2				
Steam turbine	539,889	414,676	915,079	968
Gas turbine	26,886	41,154	58,169	232
Combined cycle	16,075	23,221	29,053	227
Diesel engine	178	320	706	320
Coal-fired	–	396,004	–	396,004
Total	583,028	875,375	1,003,007	397,750
NO_x				
Steam turbine	122,411	121,454	268,016	110,442
Gas turbine	119,144	181,926	257,139	138,664
Combined cycle	91,616	159,706	199,821	135,398
Diesel engine	2711	4865	10,736	4865
Coal-fired	–	148,145	–	148,145
Total	335,883	616,097	735,712	537,514
CO				
Steam turbine	26,277	26,860	59,273	33,092
Gas turbine	19,317	29,453	41,629	35,533
Combined cycle	16,786	31,279	39,136	34,696
Diesel engine	584	1048	2313	1048
Coal-fired	–	5698	–	5698
Total	62,964	94,338	142,351	110,066

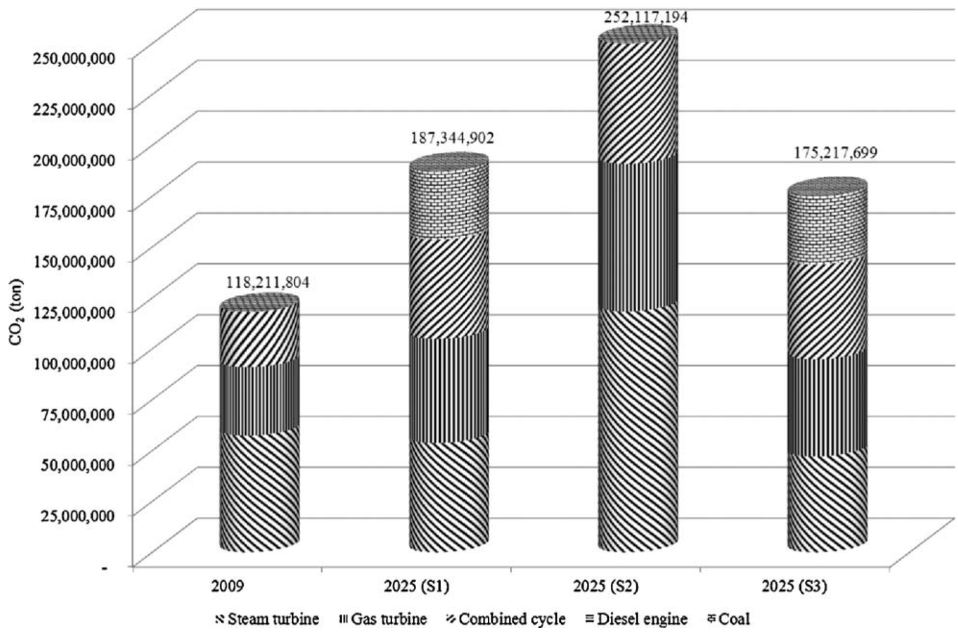

Fig. 12. CO_2 emission for each type of power plants in 2009 and three scenarios in 2025.

in 2025 which almost equal to 12 Mtons compare to the first scenario.

4.8.2. SO_2 emission

The results of SO_2 emission in different scenarios are presented in Fig. 13. The rate of SO_2 in the new power plant composition will increase by 50% and in the second scenario will be up to 72% compared with the amount in 2009. In the third scenario by eliminating or reducing the use of sulfur-containing fuels such as fuel oil and diesel, the amount of emission decreased 55% compared with the use of the new composition and 32% less than the amount in 2009. In this scenario the SO_2 emission is mostly due to coal-fired power plants, because of using huge volume of coal, which containing large amounts of sulfur. In order to reduce SO_2 emission other methods such as elimination or reduction of sulfur in the fuel or using the flue gas desulfurization (FGD) for removing SO_2 from the exhaust flue gases should be adopted [53].

4.8.3. NO_x emission

NO_x emission by power plants in different scenarios is given in Fig. 14. The results show that NO_x emission will increase 83% until

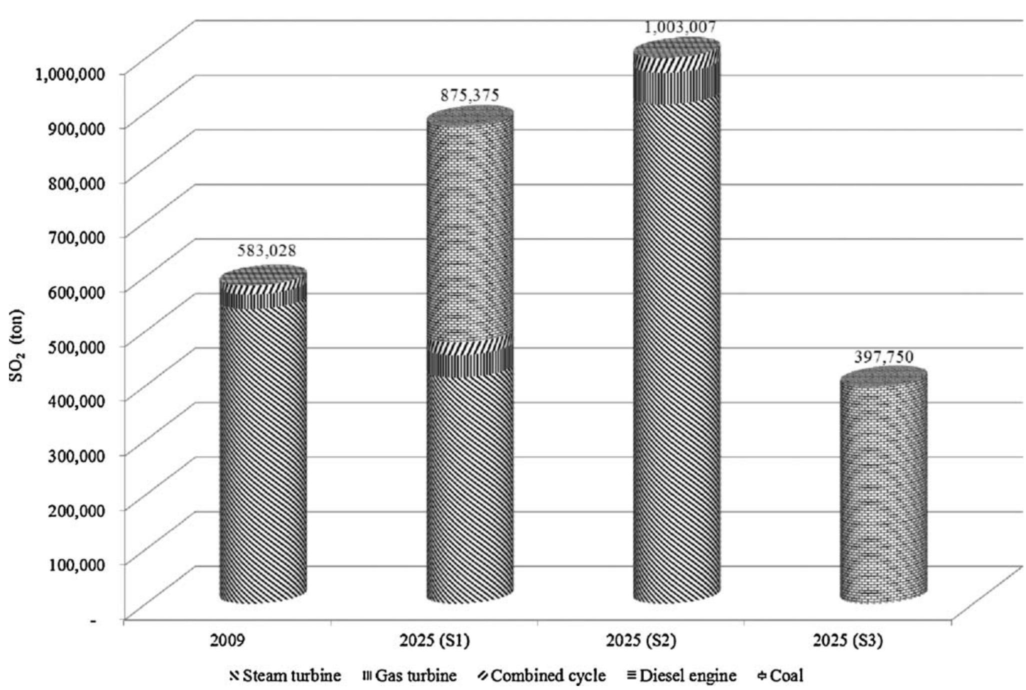

Fig. 13. SO_2 emission for each type of power plants in 2009 and three scenarios in 2025.

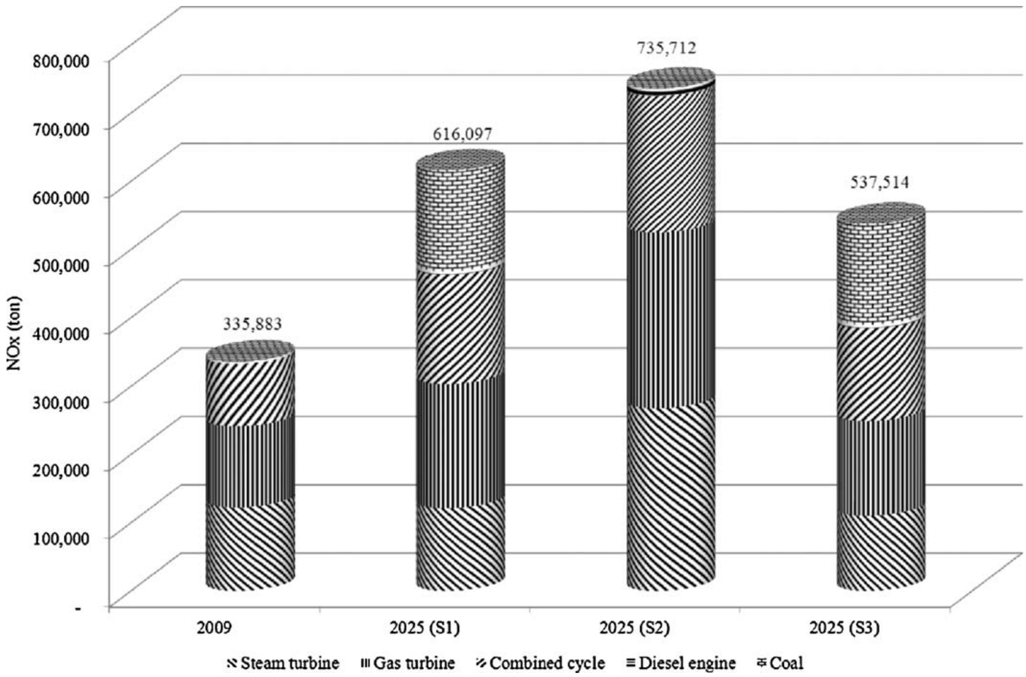

Fig. 14. NO_x emission for each type of power plants in 2009 and three scenarios in 2025.

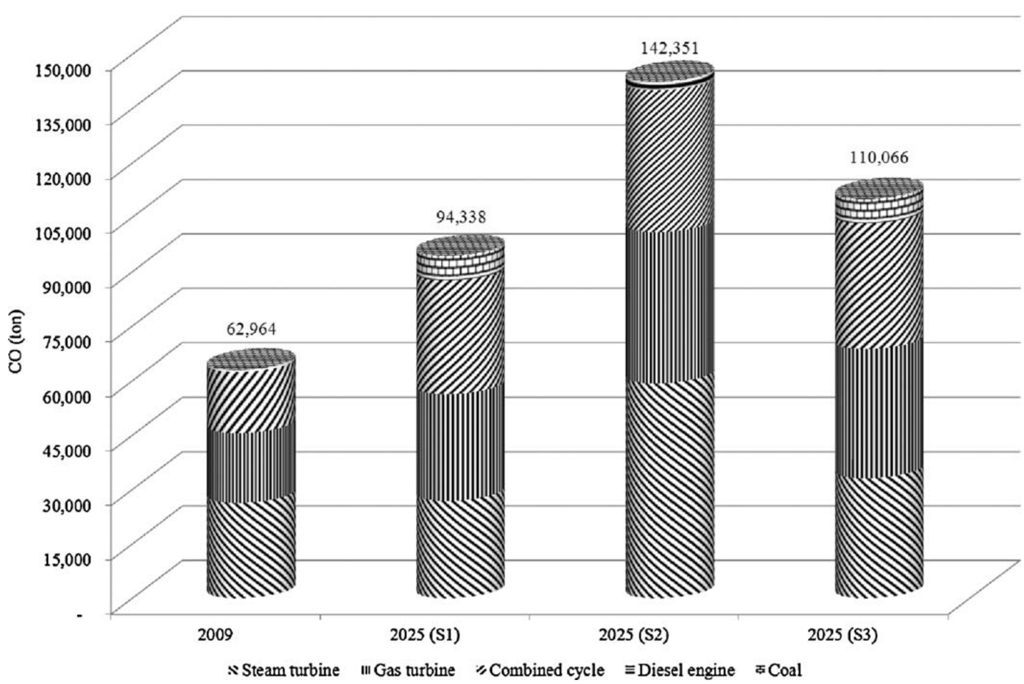

Fig. 15. CO emission for each type of power plants in 2009 and three scenarios in 2025.

2025 for the new power plant composition and if the composition does not change, this will increase to 119%. By natural gas substitution, the NO_x emission will decrease about 13% in comparison with the first scenario.

4.8.4. CO emission

CO emission in each scenario is shown in Fig. 15. The figure shows that the amount of CO emission in the first scenario will be 1.5 times higher and in the second scenario 2.3 times higher than the amount in 2009. Therefore, for CO emission, it seems that new power plant structure is better than the old ones. Nevertheless, if liquid petroleum is replaced by natural gas, the power plants will produce more CO emission about 17% higher than the first scenario or equivalent to 1.7 times in 2009.

5. Conclusion

For sustainable development and increasing energy security, the government plans to increase power plant diversity by using new types such as nuclear, coal and more renewable energies. Gov-

ernment also wants to change the structure of power industries with fewer shares of fossil fuel bases. In reality, because of technical, economical or lack of fuel supply and some other factors, the power sector of the country may develop differently. In this study, two other alternative scenarios were considered to understand the condition of fuel consumption and emissions in the future.

Iran's historical power capacity in the past years used in the polynomial curve fitting method to predict its capacity in the future. Accordingly, the total capacity estimated to be about 124 GW in 2025 equal to annual increase of 5.1%. Based on this capacity, the study shows that in the new power plant composition, despite using more hydro, renewable and nuclear power plants, the consumption of natural gas and diesel will increase by 47% and 50% respectively in comparison with the consumption in 2009. In addition, coal consumption in coal-fired power plants will be 10,826 ktons in 2025. The results also show that if Iran does not change to power plant mix and use the same composition of power plants as used in 2009, all types of fuel consumption will increase by 130%, 106% and 63% for natural gas, diesel and fuel oil respectively.

This study also indicates that if the power plant composition does not change the CO_2 emission in 2025 will be 252 Mtons and SO_2, NO_x and CO emissions will increase to 72%, 119% and 126% respectively in comparison with the amount in 2009. In the new composition, although share of thermal power plant in total capacities will decrease, the total emissions will increase to 187 Mtons, 875 ktons, 616 ktons and 94 ktons for CO_2, SO_2, NO_x and CO respectively. The positive side is the ability to achieve emission reductions by switching to low carbon fuels as described in an alternative scenario. It is found that by substitution liquid petroleum fuels by natural gas in the new composition, Iran can decrease the emissions of CO_2 by 6%, SO_2 by 55% and NO_x by 13%.

Based on the study, the suggestions to reduce emissions in Iranian thermal power plants are:

- Reduction in the share of coal-fired power plants or using techniques to diminish the harmful effects of coal consumption.
- Use of more combined cycles as a higher efficiency in thermal power plants.
- Substitution of liquid fuels with natural gas as a major fuel and supply it in most thermal power plants over the year.
- Improvement and increasing efficiency in production, transmission and distribution of electricity.

References

[1] Khosroshahi KA, Jadid S, Shahidehpour M. Electric power restructuring in Iran: achievements and challenges. The Electricity Journal 2009;22(2):74–83.
[2] Mazandarani A, Mahlia TMI, Chong WT, Moghavvemi M. A review on the pattern of electricity generation and emission in Iran from 1967 to 2008. Renewable and Sustainable Energy Reviews 2010;14(7):1814–29.
[3] TAVANIR. Conversion gas turbine power plants to combined cycle. 2009. Available from: http://news.tavanir.org.ir/press/press_detail.php?id=11619 [cited 01 Apr 2010, in Persian].
[4] Squalli J. Electricity consumption and economic growth: bounds and causality analyses of OPEC members. Energy Economics 2007;29(6):1192–205.
[5] Energy Information Administration. Iran energy data, statistics and analysis—oil, gas, electricity, coal; 2010.
[6] Ministry of Energy. Iranian energy balance sheet, yearbook 1386(2007). Tehran; 2008 [in Persian].
[7] Hessari FA. Sectoral energy consumption in Iran. Renewable and Sustainable Energy Reviews 2005;9(2):203–14.
[8] Karbassi AR, Abduli MA, Mahin Abdollahzadeh E. Sustainability of energy production and use in Iran. Energy Policy 2007;35(10):5171–80.
[9] Nakata T. Energy-economic models and the environment. Progress in Energy and Combustion Science 2004;30(4):417–75.
[10] Holttinen H, Tuhkanen S. The effect of wind power on CO_2 abatement in the Nordic Countries. Energy Policy 2004;32(14):1639–52.
[11] Romeo LM, Calvo E, Valero A, De Vita A. Electricity consumption and CO_2 capture potential in Spain. Energy 2009;34(9):1341–50.
[12] Nguyen NT, Ha-Duong M. Economic potential of renewable energy in Vietnam's power sector. Energy Policy 2009;37(5):1601–13.
[13] Gnansounou E, Dong J, Bedniaguine D. The strategic technology options for mitigating CO_2 emissions in power sector: assessment of Shanghai electricity-generating system. Ecological Economics 2004;50(1–2):117–33.
[14] Oh TH, Chua SC. Energy efficiency and carbon trading potential in Malaysia. Renewable and Sustainable Energy Reviews 2010;14(7):2095–103.
[15] International Energy Agency (IEA). Key world energy statistics 2009. Paris; 2010.
[16] Lior N, Chair P. Brief summary of the ECOS '05 panel on "future power generation". Energy 2007;32(4):254–60.
[17] International Atomic Energy Agency. The status of nuclear power plants. 2010. Available from: http://www.iaea.or.at/programmes/a2/ [cited 2 Apr 2010].
[18] International Atomic Energy Agency. Energy, electricity and nuclear power: developments and projections—25 years past and future. Vienna; 2007.
[19] Ghorashi AH. Prospects of nuclear power plants for sustainable energy development in Islamic Republic of Iran. Energy Policy 2007;35(3):1643–7.
[20] ISCA Agency. Development of nuclear power plants is the major goal of Iran. 2009. Available from: http://iscanews.ir/fa/ShowNewsItem.aspx?NewsItemID=265315 [cited 1 Mar 2010, in Persian].
[21] TAVANIR. Forth 5-year plan in electricity sector. 2009. Available from: http://www.tavanir.org.ir/info/stat85/sanatfhtml/Future.htm [cited 1 Aug 2010, in Persian].
[22] MehrNews Agency. 2.5 times increase in fuel production capacity at Natanz with new centrifuges. 2009. Available from: http://www.mehrnews.com/fa/NewsDetail.aspx?NewsID=857500 [cited 1 Aug 2010, in Persian].
[23] World Nuclear Association. Nuclear energy in Iran. 2010. Available from: http://www.world-nuclear.org/info/inf119_nucleariran.html [cited May 2010].
[24] Minstry of Energy. Development of coal-fired power plants. 2009. Available from: http://news.moe.org.ir/vdcf.cdciw6dyegiaw.html [cited 1 Aug 2010, in Persian].
[25] MehrNews Agency. Extraction and exploitation all hydrp-power capacity. 2008. Available from: http://www.mehrnews.com/fa/newsdetail.aspx?NewsID=805443 [cited 1 Mar 2010, in Persian].
[26] Iran Water & Power Resources Developement Co. Process of study, execution and operation projects. 2009. Available from: http://en.iwpco.ir/Gains.aspx [cited 1 Apr 2010].
[27] Mostafaeipour A, Mostafaeipour N. Renewable energy issues and electricity production in Middle East compared with Iran. Renewable and Sustainable Energy Reviews 2009;13(6–7):1641–5.
[28] Energy Information Administration. International energy outlook 2008. Washington, DC; 2009. p. 85.
[29] Ghobadian B, Najafi G, Rahimi H, Yusaf TF. Future of renewable energies in Iran. Renewable and Sustainable Energy Reviews 2009;13(3):689–95.
[30] PENN. Share of electricity produced from renewable sources in 2009. 2008. Available from: http://www.irpetro.com/newsdetail-609-fa.html [cited 1 Mar 2010, in Persian].
[31] Ministry of Energy News Agency. Renewable sources to account for 3% of the country's electricity generation. 2010. Available from: http://news.moe.org.ir/vdcaaon6.49nou1gtk4.html [cited 22 Aug 2010].
[32] Renewable Energy Organization of Iran. Wind atlas map of Iran. 2010. Available from: http://www.suna.org.ir/ationoffice-windenergyoffice-windatlasmap-fa.html [cited 26 May 2010].
[33] GWEC. Global wind report. 2006. p. 51.
[34] Ameri M, Ghadiri M, Hosseini M. Recent Advances in the implementation of Wind Energy in Iran. In: The 2nd joint international conference on sustainable energy and environment (SEE 2006). 2006.
[35] Center for Environment and Energy Research and Studies. Climate policy and sustainable development: opportunities for Iranian – German cooperation. Case study: solar thermal energy in Iran; 2005.
[36] Minstry of Energy. Energy in Iran, 2006. Tehran: Power and Energy Planning Department, Deputy for Energy and Electricity Affairs; 2008.
[37] Hosseini R, Soltani M, Valizadeh G. Technical and economic assessment of the integrated solar combined cycle power plants in Iran. Renewable Energy 2005;30(10):1541–55.
[38] Yaghoubi M, Azizian K, Kenary A. Simulation of Shiraz solar power plant for optimal assessment. Renewable Energy 2003;28(12):1985–98.
[39] Noorollahi Y, Yousefi H, Itoi R, Ehara S. Geothermal energy resources and development in Iran. Renewable and Sustainable Energy Reviews 2009;13(5):1127–32.
[40] Fadai D. Utilization of renewable energy sources for power generation in Iran. Renewable and Sustainable Energy Reviews 2007;11(1):173–81.
[41] Lavizeh F. General report on geothermal and related fields in Iran. Tehran: Geological Survey of Iran; 2002.
[42] Schwartz P. The art of the long view: planning in an uncertain world. New York: Doubleday; 1996.
[43] Bianco V, Manca O, Nardini S. Electricity consumption forecasting in Italy using linear regression models. Energy 2009;34(9):1413–21.
[44] Klienbaum, Kupper, Nizam, Muller. Applied regression analysis and other multivariable methods. 4th ed. USA: Thomson Higher Education; 1998.
[45] U.S. Environmental Protection Agency. Emissions factors & AP 42, vol. I, 5th ed. Available from: http://www.epa.gov/ttn/chief/ap42/index.html [cited May 24, 2010].
[46] TAVANIR. Statistical reports on 43 years of activities of Iran electric power industry (1967–2009). Tehran; 2010.

[47] Ghiasedding M. Air pollution emitted from fossil fuel power plants. Tehran: Niroo Research Institute; 2001 [in Persian].
[48] Research Institute of Petroleum Industry. Designing the first industrial unit aids deep desulphurization from diesel oil by UDHDS technology. 2008. Available from: http://pananews.ir/print/?id=94 [cited 20 July 2009, in Persian].
[49] Mahlia TMI. Emissions from electricity generation in Malaysia. Renewable Energy 2002;27(2):293–300.
[50] Steenhof PA, Fulton W. Factors affecting electricity generation in China: current situation and prospects. Technological Forecasting and Social Change 2007;74(5):663–81.
[51] Energy Information Administration. Average capacity factors by energy source. 2010. Available from: http://www.eia.doe.gov/cneaf/electricity/epa/epata6.html [cited 25 Aug 2010].
[52] Nazari S, et al. Experimental determination and analysis of CO_2, SO_2 and NO_x emission factors in Iran's thermal power plants. Energy 2010;35(7):2992–8.
[53] Wikipedia. Flue-gas desulfurization. 2010. Available from: http://en.wikipedia.org/wiki/Flue-gas_desulfurization [cited 10 Apr 2010].